CLAIMS

1. An ultrasonic apparatus for measuring the concentration and flow rate of a sample gas, comprising:

a conduit for flowing the sample gas;

a first ultrasonic transmission-reception device mounted to the inside of the conduit;

a second ultrasonic transmission-reception device mounted to the inside of the conduit to face the first ultrasonic transmission-reception device;

a transmission-reception switch for switching the operation mode of the first and second ultrasonic transmission-reception devices between a transmission mode for transmitting ultrasonic waves and a reception mode for receiving ultrasonic waves;

a temperature sensor, disposed in the conduit, for measuring the temperature of the sample gas flowing through the conduit;

the first ultrasonic transmission-reception device generating forward ultrasonic waves relative to the flow direction of the sample gas when the device is in the transmission mode and generating backward waveform when the device is in the reception mode on the basis of the received ultrasonic waves generated by the second ultrasonic transmission-reception device;

the second ultrasonic transmission-reception device generating backward ultrasonic waves relative to the flow direction of the sample gas when the device is in the transmission mode and generating forward waveform when the device is in the reception mode on the basis of the received ultrasonic waves generated by the first ultrasonic transmission-reception device;

means for generating trigger signals when the forward and backward waveforms pass over a predetermined level;

means for generating forward and backward zero-cross signals when the forward and backward

waveforms pass over a zero level;

propagation time calculation means, coupled to the temperature sensor, the trigger signal generating means and the zero-cross signal generating means, for (1) calculating a possible propagation time range on the basis of the gas temperature detected by the temperature sensor, (2) determining whether or not the phases at which two first trigger signals, respectively generated on the basis of the forward and backward waveforms, coincide with each other, (3) processing the zero-cross signals so that the phases coincide with each other if they do not coincide with each other, (4) obtaining reference zero-cross time instant by calculating mean value of the forward and backward zero-cross time instants, (5) obtaining an ultrasonic reception point by subtracting an integral multiple of the cycle of the ultrasonic waves so that the results of the subtraction falls into the possible propagation time range and (6) estimating the ultrasonic propagation time on the basis of the ultrasonic reception point.

2. An ultrasonic apparatus according to claim 1 wherein the distance along the conduit between first and second ultrasonic transmission-reception devices is selected so that only one result of the subtraction falls into the possible propagation time range determined over possible working conditions of the ultrasonic apparatus.

3. An ultrasonic apparatus according to claim 2 wherein the distance along the conduit between first and second ultrasonic transmission-reception devices is sleeted to satisfy the following relation.

$$(L_s/C_{min}(T_{min}) - L_s/C_{max}(T_{min})) < 1/f$$

where:

f: frequency of the ultrasonic waves in the sample gas

$C_{min}(T_{min})$: the lower limit of the ultrasonic velocity (m/sec) through the sample gas at the lowest working temperature T_{min} (Celsius degrees)

$C_{max}(T_{min})$: the upper limit of the ultrasonic velocity (m/sec) through the sample gas at the lowest working temperature T_{min} (Celsius degrees)

4. An ultrasonic apparatus according to claim 1 wherein the inner radius of the conduit is selected so that the difference between the forward and backward propagation time is smaller than the cycle of the ultrasonic waves under the working condition of the sample gas.

5. An ultrasonic apparatus according to claim 1 wherein the inner radius of the conduit is selected to satisfy the following relation

$$L/(C_{min}(T_{min})-Q_{max}/(60000\pi/r^2))$$
$$-L/(C_{min}(T_{min})+Q_{max}/(60000\pi/r^2))<1/f$$

where:

f: frequency of the ultrasonic waves in the sample gas

$C_{min}(T_{min})$: the lower limit of the ultrasonic velocity (m/sec) through the sample gas at the lowest working temperature T_{min} (Celsius degrees)

Q_{max}: the upper limit of the sample gas flow rate (litter/min)

6. An ultrasonic apparatus according to claim 1 wherein the conduit includes a straight potion and perpendicular portions perpendicularly connected to the ends of the straight portion;

the first and second ultrasonic transmission-reception devices are disposed in the perpendicular portions to face the ends of the straight portion; and

the distance between the first and second ultrasonic transmission-reception devices and the respective ends of the straight portion of the conduit satisfying the following relation.

$$0<D<f-r^2/C$$

D: the distance (m) between the first and second

ultrasonic transmission-reception devices and the respective ends of the straight portion

f: frequency of the ultrasonic waves in the sample gas (Hz)

r: inner radius of the conduit (m)

C: velocity of the ultrasonic waves (m/sec)

7. A method of measuring the concentration of sample gas flowing through a conduit, comprising the steps of:

generating forward ultrasonic waves relative to the flow direction of the sample gas;

generating backward ultrasonic waves relative to the flow direction of the sample gas;

measuring the temperature of the sample gas flowing through the conduit;

generating trigger signals when the forward and backward waveforms pass over a predetermined level;

generating forward and backward zero-cross signals when the forward and backward waveforms pass over a zero level;

calculating a possible propagation time range on the basis of the gas temperature detected by the temperature sensor;

determining whether or not the phases at which two first trigger signals, respectively generated on the basis of the forward and backward waveforms, coincide with each other;

processing the zero-cross signals so that the phases coincide with each other if they do not coincide with each other;

obtaining reference zero-cross time instant by calculating mean value of the forward and backward zero-cross time instants;

obtaining an ultrasonic reception point by subtracting an integral multiple of the cycle of the ultrasonic waves so that the results of the subtraction

falls into the possible propagation time range; and

estimating the ultrasonic propagation time on the basis of the ultrasonic reception point.

8. A method according to claim 7 wherein the forward and backward ultrasonic waves are transmitted and received by first and second ultrasonic transmission-reception devices which are disposed in the conduit, the distance along the conduit between first and second ultrasonic transmission-reception devices being selected so that only one result of the subtraction falls into the possible propagation time range determined over possible working conditions of the ultrasonic apparatus.

9. A method according to claim 8 wherein the distance along the conduit between first and second ultrasonic transmission-reception devices is sleeted to satisfy the following relation.

$$(L_s/C_{min}(T_{min}) - L_s/C_{max}(T_{min})) < 1/f$$

where:

f: frequency of the ultrasonic waves in the sample gas

$C_{min}(T_{min})$: the lower limit of the ultrasonic velocity (m/sec) through the sample gas at the lowest working temperature T_{min} (Celsius degrees)

$C_{max}(T_{min})$: the upper limit of the ultrasonic velocity (m/sec) through the sample gas at the lowest working temperature T_{min} (Celsius degrees)

10. A method according to claim 7 wherein the inner radius of the conduit is selected so that the difference between the forward and backward propagation time is smaller than the cycle of the ultrasonic waves under the working condition of the sample gas.

11. A method according to claim 7 wherein the inner radius of the conduit is selected to satisfy the following relation

$$L/(C_{min}(T_{min})-Q_{max}/(60000\pi/r^2))$$
$$-L/(C_{min}(T_{min})+Q_{max}/(60000\pi/r^2))<1/f$$

where:

f: frequency of the ultrasonic waves in the sample gas

$C_{min}(T_{min})$: the lower limit of the ultrasonic velocity (m/sec) through the sample gas at the lowest working temperature T_{min} (Celsius degrees)

Q_{max}: the upper limit of the sample gas flow rate (litter/min)

12. An oxygen concentration system for generating an oxygen enriched gas, comprising

an oxygen concentration apparatus for generating an oxygen enriched gas by adsorbing nitrogen to remove the nitrogen from the air; and

an ultrasonic apparatus for measuring the concentration of the oxygen in the oxygen enriched gas and flow rate of the oxygen enriched gas, the ultrasonic apparatus comprising:

a conduit for receiving and flowing the oxygen enriched gas;

a first ultrasonic transmission-reception device mounted to the inside of the conduit;

a second ultrasonic transmission-reception device mounted to the inside of the conduit to face the first ultrasonic transmission-reception device;

a transmission-reception switch for switching the operation mode of the first and second ultrasonic transmission-reception devices between a transmission mode for transmitting ultrasonic waves and a reception mode for receiving ultrasonic waves;

a temperature sensor, disposed in the conduit, for measuring the temperature of the oxygen enriched gas flowing through the conduit;

the first ultrasonic transmission-reception device generating forward ultrasonic waves relative to the flow direction of the oxygen enriched gas when the device is in the transmission mode and generating backward waveform when the device is in the

reception mode on the basis of the received ultrasonic waves generated by the second ultrasonic transmission-reception device;

the second ultrasonic transmission-reception device generating backward ultrasonic waves relative to the flow direction of the oxygen enriched gas when the device is in the transmission mode and generating forward waveform when the device is in the reception mode on the basis of the received ultrasonic waves generated by the first ultrasonic transmission-reception device;

means for generating trigger signals when the forward and backward waveforms pass over a predetermined level;

means for generating forward and backward zero-cross signals when the forward and backward waveforms pass over a zero level;

propagation time calculation means, coupled to the temperature sensor, the trigger signal generating means and the zero-cross signal generating means, for (1) calculating a possible propagation time range on the basis of the gas temperature detected by the temperature sensor, (2) determining whether or not the phases at which two first trigger signals, respectively generated on the basis of the forward and backward waveforms, coincide with each other, (3) processing the zero-cross signals so that the phases coincide with each other if they do not coincide with each other, (4) obtaining reference zero-cross time instant by calculating mean value of the forward and backward zero-cross time instants, (5) obtaining an ultrasonic reception point by subtracting an integral multiple of the cycle of the ultrasonic waves so that the results of the subtraction falls into the possible propagation time range and (6) estimating the ultrasonic propagation time on the basis of the ultrasonic reception point.

13. An ultrasonic apparatus according to claim 12

wherein the distance along the conduit between first and second ultrasonic transmission-reception devices is selected so that only one result of the subtraction falls into the possible propagation time range determined over possible working conditions of the ultrasonic apparatus.

14. An ultrasonic apparatus according to claim 13 wherein the distance along the conduit between first and second ultrasonic transmission-reception devices is sleeted to satisfy the following relation.

$$(L_s/C_{min}(T_{min}) - L_s/C_{max}(T_{min})) < 1/f$$

where:

f: frequency of the ultrasonic waves in the sample gas

$C_{min}(T_{min})$: the lower limit of the ultrasonic velocity (m/sec) through the oxygen enriched gas at the lowest working temperature T_{min} (Celsius degrees)

$C_{max}(T_{min})$: the upper limit of the ultrasonic velocity (m/sec) through the oxygen enriched gas at the lowest working temperature T_{min} (Celsius degrees)

15. An ultrasonic apparatus according to claim 12 wherein the inner radius of the conduit is selected so that the difference between the forward and backward propagation time is smaller than the cycle of the ultrasonic waves under the working condition of the oxygen enriched gas.

16. An ultrasonic apparatus according to claim 12 wherein the inner radius of the conduit is selected to satisfy the following relation

$$L/(C_{min}(T_{min})-Q_{max}/(60000\pi/r^2)) \\ -L/(C_{min}(T_{min})+Q_{max}/(60000\pi/r^2))<1/f$$

where:

f: frequency of the ultrasonic waves in the sample gas

$C_{min}(T_{min})$: the lower limit of the ultrasonic velocity (m/sec) through the oxygen enriched gas at the lowest working temperature T_{min} (Celsius degrees)

Q_{max}: the upper limit of the oxygen enriched gas flow rate (litter/min)

17. An ultrasonic apparatus according to claim 12 wherein the conduit includes a straight potion and perpendicular portions perpendicularly connected to the ends of the straight portion;

the first and second ultrasonic transmission-reception devices are disposed in the perpendicular portions to face the ends of the straight portion; and

the distance between the first and second ultrasonic transmission-reception devices and the respective ends of the straight portion of the conduit satisfying the following relation.

$$0<D<f\cdot r^2/C$$

D: the distance (m) between the first and second ultrasonic transmission-reception devices and the respective ends of the straight portion

f: frequency of the ultrasonic waves in the sample gas (Hz)

r: inner radius of the conduit (m)

C: velocity of the ultrasonic waves (m/sec)

18. An ultrasonic apparatus according to claim 12 wherein the conduit is secured to the oxygen concentration apparatus at one point to allow the conduit to thermally expand in the longitudinal direction of the straight portion freely from external force which may be generated when the conduit is thermally deformed.

19. An oxygen concentration system for generating an oxygen enriched gas, comprising:

an oxygen concentration apparatus for generating an oxygen enriched gas by adsorbing nitrogen to remove the nitrogen from the air; and

an ultrasonic apparatus for measuring the concentration of the oxygen in the oxygen enriched gas and flow rate of the oxygen enriched gas, the ultrasonic apparatus comprising:

a conduit for flowing an objective gas, the concentration of which is to be measured;

a first ultrasonic transmission-reception device mounted to the inside of the conduit;

a second ultrasonic transmission-reception device mounted to the inside of the conduit to face the first ultrasonic transmission-reception device;

the conduit includes a straight potion and perpendicular portions perpendicularly connected to the ends of the straight portion;

the first and second ultrasonic transmission-reception devices are disposed in the perpendicular portions to face the ends of the straight portion; and

the distance between the first and second ultrasonic transmission-reception devices and the respective ends of the straight portion of the conduit satisfying the following relation.

$$0<D<f-r^2/C$$

where:

D: the distance (m) between the first and second ultrasonic transmission-reception devices and the respective ends of the straight portion

f: frequency of the ultrasonic waves in the sample gas (Hz)

r: inner radius of the conduit (m)

C: velocity of the ultrasonic waves (m/sec)

20. An oxygen concentration system according to claim 19 wherein the inner diameter of the straight portion is smaller than the outer diameter of first and second ultrasonic transducers.

21. An oxygen concentration system according to claim 19 wherein the conduit is secured to the oxygen concentration apparatus by means for allowing the longitudinal deformation of the straight portion freely from external force which may be generated when the conduit is thermally deformed.

22. An oxygen concentration system according to claim 19 wherein the conduit is secured to the oxygen concentration apparatus at one point to allow the conduit to thermally expand in the longitudinal direction of the straight portion freely from external force which may be generated when the conduit is thermally deformed.